폴리디메틸실록산으로 제작된 경사 전극을 가진 2축 구동 스캐닝 미러의 설계 및 제작

진주영*, 박재형**, 유병욱*, 장윤호*, 박일흥**, 김용권*
*서울대학교 전기컴퓨터공학부, **이화여자대학교 물리학과

Design and fabrication of 2-DOF scanning mirror with Polydimethylsiloxane sloped electrode

J.Y. Jin*,J.H.Park**,B.W.Yoo*, Yun-Ho Jang*, I.H.Park**,and Y.K.Kim*
*School of Electrical Engineering and Computer Science, Seoul National University
**Department of Physics, Ewha Womans University

Abstract - In this paper, we present a simple fabrication process for sloped electrodes in 2-degree of fredom(DOF) scanning micromirror employing pholydimethylsiloxane(PDMS). Using this process, quasi-conic figure electrode is successfully fabricated on the substrate. Simulation results show sloped electrodes decrease actuation voltage down to 22% compared with parallel plate type of electrodes having the same electrode area.

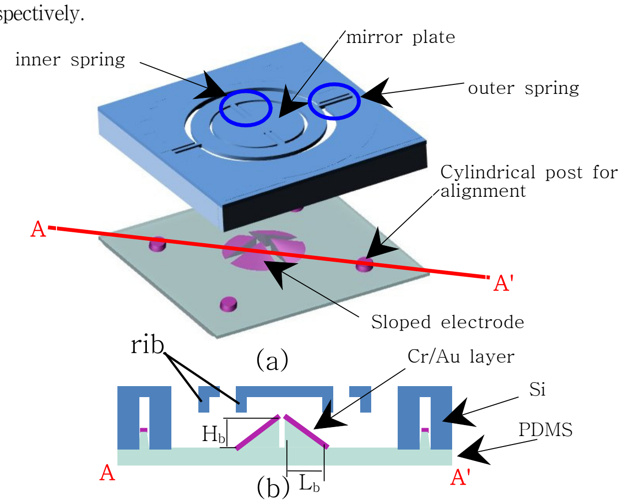
1. INTRODUCTION

The electrostatic actuators are one of the popular schematic because it provides simple process and structure. Among them, parallel plate actuator is widely used due to the simplicity of fabrication. A major problem of parallel plate actuator, however, is the pull-in instability tending to limit the stable travel range. In order to increase the range, it is required to widen the gap between electrodes consequently resulting in large actuation voltage. To overcome this problem, a sloped electrode is proposed previously[1]. Micromirrors which Ming C. Wu demonstrated need not only complicateed fabricationi process, but can also be unfit for large display unit. With PDMS employed for the sloped electrode substrate, we can achieve simple process and large scale micromirror.

2. SUBJECT

2.1 DESIGN

As can be seen in Figure 1, the proposed scanning micromirror consists of two layers, i.e. a mirror plate layer and an electrode layer. Mirror plate layer employs single crystal silicon for structural stability and is composed of gimbal, tilting springs and posts. The gimbal structure allows the mirror plate to rotate along two orthogonal axes. A reflective mirror plate has 4 mm diameter and 50 µm thickness. Tilting springs are also 50 µm thickness and 15 µm width, but 1000 µm length in inner springs and 1200 µm in outer springs. Beneath the mirror plate, ribs are attached for improving flatness ,and its width and thickness are 50 µm and 100 µm, respectively.



<Figure 1> Schematics of scanning micromirror, (a) overall view, (b) cross sectional view.

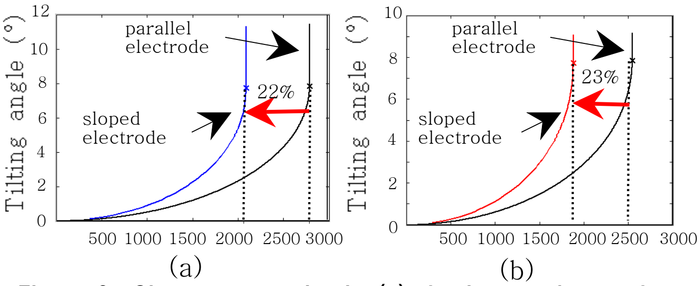
Meanwhile the electrode layer is made of PDMS and composed of four quasi-cone figure to enable mirror plate to rotate along the 2-axes. Each electrode is seperated by 500 µm gap each other. Bottom length(L_b) is 1.15 mm and height(H_b) is 300 µm.

A analytical model of the sloped electrode is calculated in previous work[2] as following equation (1) and (2),

$$T_e = \frac{\pi}{2}\epsilon_0 \frac{L_m^2}{Z_0^2} V_a^2 i(\alpha,\beta) \quad (1)$$

$$i(\alpha,\beta) = (1-\beta)\sqrt{L_e^2+Z_0^2}\left[\frac{1}{\alpha}ln(-\alpha\beta+1)+\frac{1}{\alpha}\frac{1}{-\alpha+1/\beta}\right] \quad (2)$$

where V_a is applied voltage, Z_0 is cavity size, L_e is electrode length, α is normalized tilt angle, and β is gap on electrode length ratio. Although the travel range decreased down to 2.5% as shown in Figure 2, actuation voltage is decreased 22% in inner axis, and 23% in outer axis compared with parallel plate electrode.(Figure 2).

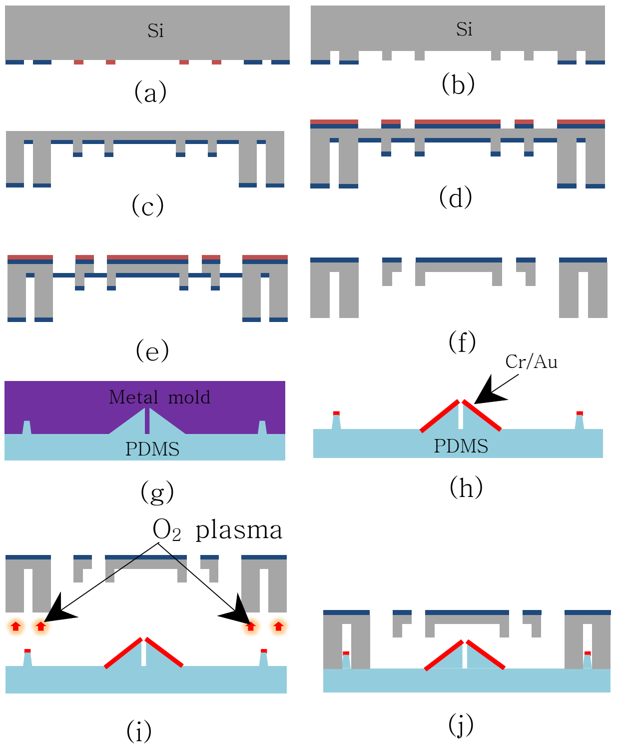


<Figure 2> Simulation results in (a) the inner axis , and (b) the outer axis.

2.2 FABRICATION

Figure 3 shows a fabrication process. The mirror plate layer and the electrode layer are fabricated separately, and then bonded to each other. Mirror plate layer is made of a single crystal silicon wafer. A 5000 Å Al film and photoresist(AZ4330) is patterned on the wafer. After a deep reactive-ion-etching(Deep-RIE) process is performed to build up ribs, PR is eliminated and Deep-RIE is processed again to dig a cavity to secure space for the mircromirror angular motion. After Al mask is removed through wet etchant, inter-metal layer of 2500 Å Al is deposited beneath the mirror plate. It is used to prevent from isotropic etch in the following Deep-RIE process, which is caused by low thermal conductivity of air in the cavity. In the opposite side, 1500 Å Al is deposited and then etched with PR mask. After wafer is diced amount of 170 µm thickness. Deep-RIE process is followed until Al inter-meal layer is revealed. Dipping to the Al etchant is followed to release the micromirror.

The electrode layer is fabricated with metal mold, which is produced by mechanical manufacturing. With PDMS poured into it, PDMS is cured at 80 °C for 1.5 hr in atmospheric pressure. And then using shadow mask of 0.5 mm thickness, Cr/Au address line is deposited on the PDMS substrate. A metal sputtering process is chosen to deposit metal film because thermal evaporation and e-beam evaporation generates evaporated sources of high temperature, and it attacks the PDMS surface. The mirror plate layer and the electrode layer are bonded through O_2 plasma treatment with the RIE 80 plus(Oxford instrument) for 2 min on the silicon surface. Cylindrical columns are used for alignment between the mirror plate and the electrode layer.

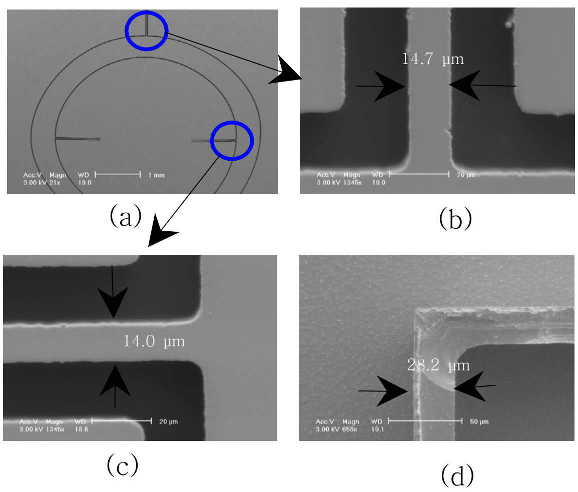


<Figure 3> Fabrication process. (a)Al and PR patterning, (b) Deep-RIE and PR removal, (c) Deep-RIE and Al dep., (d) Al dep., PR patterning and Al dry etch, (e) Deep-RIE, (f) Al wet etch for release, (g)PDMS molding,(h)Cr/Au dep., (i) O_2 plamsa treatment, (j)Bonding

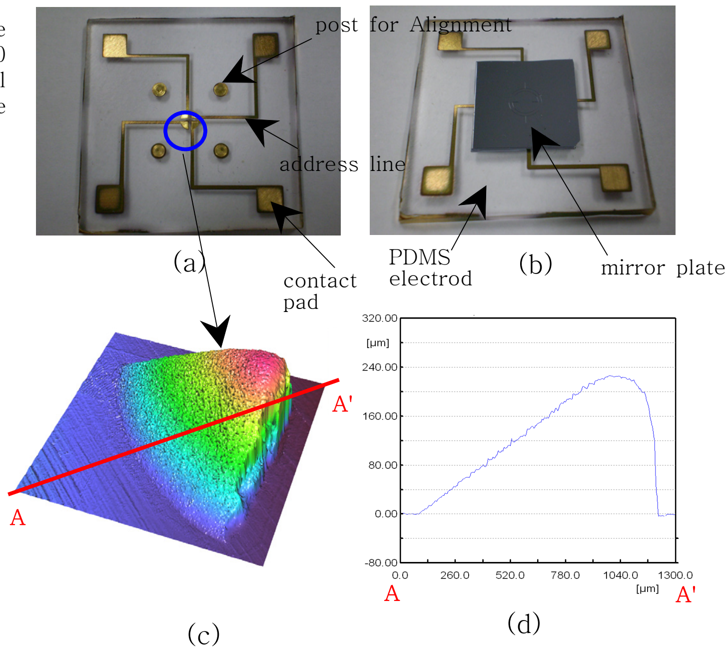
2.3. FABRICATION RESULTS

Figure 4 shows field emission scanning electrode microscope (FESEM) images of the fabricated mirror plate. Dimensions of fabricated springs corrspond with designed values. The inner spring is measured to be 14.0 μm width and 997 μm length, and outer 14.7 μm width and 1196 μm length. But the width of the rib is 28.2 μm which is almost half of designed value due to isotropic etch during the deep-RIE process. We employed 5/3/15 recipe in Bosch process to prevent growing silicon grass.

Fabricated electrode is also in Figure 5. Average electrical resistance

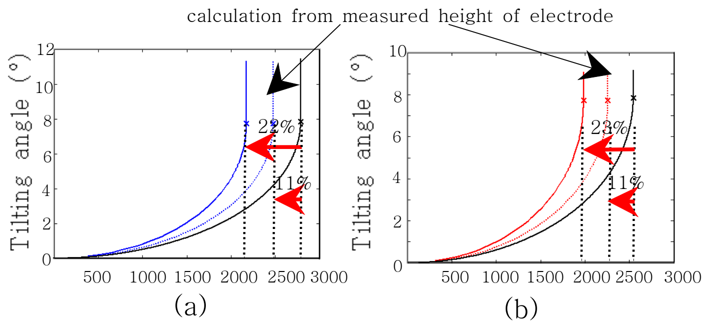


<그림 4> FESEM images of the mirror plate, (a) top view, (b)outer spring, (c) inner spring, (d) rib.



<Figure 5> Fabrication results of (a) PDMS sloped electrode layer, (b) completed device, (c) 3D profile image of sloped electrode and (d) its 2D profile.

of each address line is 1.18 kΩ. Magnified profile by 3D profiler (Figure 4(c)and (d)) presents fabricated sloped electrode figure. A smoothness is a few micrometers. But its height is 226.2 μm, that is 24.6% less than design value, and it causes the actuation voltage to be higher than designed value of sloped electrodes. Simulation result which is calculated based on the measured height in Figure 6 ilustrates actuation volage increase. With Comparing with parallel plate electrode, actuation voltage is decreased down to 11%, whereas designed one is 22% in inner axis and 22% in outer axis. Contraction of the vertex during the cure of PDMS is considered as major factor of error.



<Figure 6> Simulation results from design (solid line) and electrode height measurement(dot line) of (a) inner axis , and (b) outer axis

3. CONCLUSION

We suggested simple process to fabricate sloped electrode of large area micromirror. Analytical model is calculated and simulation results show that actuation voltage decrease of 22% in inner axis and 23% in outer axis can be expected at the cost of 2% maximum tilt angle reduction. Although the height of the sloped electrode is less than design value, PDMS substantial electrode process is successfully performed and proved.

[REFERENCE]

[1] Jui-che Tsai and Ming C. Wu, "Gimbal-Less MEMS Two-Axis Optical Scanner Array With High fill-Factor," *J Microelectromechanical Syst.*, vol. 14, no. 6, pp. 1323-1328, Dec.,2005

[2] Joo-Young, Jae-Hyoung Park, Byung-Wook Yoo, Yun-Ho Jang, and Yong-Kweon Kim, "Design and fabrication of 2-DOF scanning micromirror with slopping electrodes," *The 16th Korea conference on Semiconductors,* Dae-jeon, Korea, 2009